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(54)【発明の名称】　高温強度及び靭性に優れたダイカスト用アルミニウム合金及び製造方法

(57)【要約】

【目的】　高温強度及び靭性が改善されたダイカスト用アルミニウム合金を得る。

【構成】　このアルミニウム合金は、Ｃｕ：１～７％，Ｓｉ：１０～１６％，Ｍｇ：０．３～２％，Ｆｅ：０．５～２％，Ｍｎ：０．１～４％，Ｔｉ：０．０１～０．３％，Ｐ：０．０１％以下，Ｃａ：０．００１～０．０２％及び必要に応じてＮｉ：０．２～６％を含み、Ｐ／Ｃａが重量比で０．５以下の範囲に調整されている。冷却速度２０℃／秒以上で鋳造し、晶出物の平均長径を２０μm以下，共晶Ｓｉの平均長径を１０μm以下にする。

【効果】　初晶Ｓｉ，共晶Ｓｉ及び高融点金属晶出物の微細化により、靭性及び高温強度が改善される。

【特許請求の範囲】

【請求項1】　Cu：1～7重量%，Si：10～16重量%，Mg：0．3～2重量%，Fe：0．5～2重量%，Mn：0．1～4重量%，Ti：0．01～0．3重量%，P：0．01重量%以下及びCa：0．001～0．02重量%を含み、P／Caが重量比で0．5以下の範囲に調整されている高温強度及び靭性に優れたダイカスト用アルミニウム合金。

【請求項2】　更にNi：0．2～6重量%を含む請求項1記載の高温強度及び靭性に優れたダイカスト用アルミニウム合金。

【請求項3】　晶出物の平均長径が20μm以下及び共晶Siの平均長径が10μm以下の鋳造組織を持つ請求項1又は2記載の高温強度及び靭性に優れたダイカスト用アルミニウム合金。

【請求項4】　請求項1又は2記載の組成をもつアルミニウム合金溶湯を冷却速度20℃／秒以上でダイカストすることにより製造されるダイカスト製品の製造方法。

【請求項5】　請求項4の方法で製造されたダイカスト製品。

【発明の詳細な説明】

【0001】

【産業上の利用分野】本発明は、ディーゼルエンジン，ガソリンエンジン等の内燃機関に使用されるピストン，コンロッド，シリンダーブロック，シリンダーヘッド等として好適な高温強度及び靭性に優れたダイカスト用アルミニウム合金及びその製造方法に関する。

【0002】

【従来の技術】Siを約10重量%以上含有する共晶又は過共晶Al－Si合金は、熱膨張係数が小さく、耐摩耗性に優れている。また、Si含有量が多くなると溶湯が凝固する際に高硬度の初晶Siが晶出するため、耐摩耗性が要求される内燃機関のピストン，コンプレッサー部品等の各種機械部品として使用されている。なかでも、AC8Aが代表的なAl－Si合金として使用されている。最近の内燃機関では、エネルギー資源の有効利用から燃焼効率を上昇させる傾向にある。燃焼効率を向上させようとすると燃焼温度が上昇し、これに伴って内燃機関に組み込まれている各種部品、特にピストンの材質として200℃付近の温度域で高い高温強度が要求される。内燃機関に使用される他の部品についても、同様に耐摩耗性の向上が求められている。

【0003】高温強度を改善したピストン用アルミニウム合金としては、T_5 熱処理でも十分な高温強度及び耐熱衝撃性をもつものが特開昭57－79410号公報で紹介されている。この合金においては、Si含有量を8．5～13．5重量%の範囲に規制すると共に、Sb添加によって共晶Siを改良している。また、特開昭5造後に480～520℃に1～8時間加熱する熱処理によって耐熱衝撃性を改善している。一般に、高温強度の優れたAl－Si系材料には、ベースとなるAl－Si－Cu－Mg系合金に少量のNi，Mn，Fe，Cr，Zr等の高融点成分が含まれている。高融点成分は、溶湯が凝固する際に微小の晶出部として晶出し、Al合金の高温変形を阻止する作用を呈する。しかし、高融点成分の含有量増加に従って、粗大な金属間化合物が多量に生成し、強度を劣化させ易い。しかも、伸びが低下し、靭性の要求される部品としては、十分に満足できる特性を備えていない。

【0004】

【発明が解決しようとする課題】しかし、Al－Si系合金は、従来の合金成分の調整や添加成分による組織改良では最早材料特性を改善することができないレベルに達している。そのため、従来にはない方法で組成・組織を改善し、現状を大幅に上まわる特性、特に高温特性を示す材料の開発が必要とされている。もっとも問題にされる点としては、高温特性の改善に有効な高融点成分の添加量増加に伴い粗大な晶出物が生成し、強度劣化を起こすことである。そこで、強度劣化を伴わずに高融点成分の添加量増加によって特性の向上を図ることができれば、各種用途に要求される材料特性を満足するAl－Si系合金が得られる。本発明は、このような要求に応えるべく案出されたものであり、ダイカスト又はそれ以上の冷却速度を有する鋳造法で成分系が特定されたAl－Si系合金を鋳造することにより、高融点成分を高温で安定な微細金属間化合物として晶出させた組織とし、高温強度及び靭性に優れたアルミニウム合金を提供することを目的とする。

【0005】

【課題を解決するための手段】本発明のダイカスト用アルミニウム合金は、その目的を達成するため、Cu：1～7重量%，Si：10～16重量%，Mg：0．3～2重量%，Fe：0．5～2重量%，Mn：0．1～4重量%，Ti：0．01～0．3重量%，P：0．01重量%以下及びCa：0．001～0．02重量%を含み、P／Caが重量比で0．5以下の範囲に調整されていることを特徴とする。このアルミニウム合金は、更にNi：0．2～6重量%を含むこともできる。本発明に従ったダイカスト用アルミニウム合金は、前述した組成をもつアルミニウム合金溶湯を冷却速度20℃／秒以上で鋳造し、晶出物の平均長径を20μm以下及び共晶Siの平均長径を10μm以下に抑制している。

【0006】以下、本発明のアルミニウム合金に含まれる合金元素及びその含有量等について説明する。

Cu：1～7重量%

高温強度及び高温疲労強度の向上に有効な合金元素であ

7重量％を超える多量のCuが含まれると鋳造時にAl_2Cu等の大きな晶出物が生成し、鋳造割れが発生し易くなる。また、多量にCuを添加しても、増量に見合った強度改善の効果も得られない。

Si：10～16重量％

耐摩耗性の向上及び熱膨張係数の低減に有効な共晶Siとなる必須の合金元素であり、湯流れを良好にする作用も呈する。また、共存しているMgと反応し、時効硬化に有効なMg_2Siをも生成する。Si含有量が10重量％に達しないと、耐摩耗性や高温強度が目標値よりも低くなり、熱膨張係数が大きくなる。逆に、16重量％を超えるSi含有量では、初晶Siのサイズが大きくなり、かつ分散量も多くなる。その結果、応力集中による高温強度の低下を招く。

【0007】Mg：0．3～2重量％

Siと結合し、時効硬化に有効なMg_2Siを生成する。Mg含有量が0．3重量％に達しないと、十分な時効作用が得られない。逆に、2重量％を超えるMg含有量では、鋳造時に多量のMg_2Siが晶出し、機械的性質を低下させる。

Fe：0．5～2重量％

高温強度の向上に有効な合金元素であり、0．5重量％以上のFe含有量で効果が顕著となる。しかも、ダイカスト時における金型の焼付きを防止する。Feは、種々の金属間化合物として晶出し、高温での強度を改善する。しかし、2重量％を超えるFe含有量では、Feを含む粗大な金属間化合物が晶出するため、却って高温強度を低下させる。

Mn：0．1～4重量％

Al－Mn－Si，Al－Fe－Mn－Si系等の金属間化合物として晶出し、耐摩耗性を向上させる。また、200℃近傍における高温強度の改善にも有効な合金元素である。このような効果を得るためには、0．1重量％以上のMnが必要である。しかし、4重量％を超える多量のMn含有量では、巨大な晶出物が多量に生成するため、伸び低下等の欠陥を引き起こす。

【0008】Ti：0．01～0．3重量％

α－Alを微細化し、材質を均質化する上で有効な合金元素である。Ti含有量が0．01重量％以上になると、α－Alがマクロ結晶粒で直径10mm以下となり、微細化による効果が顕著になる。しかし、0．3重量％を超えるTi含有量では、Al－Ti系の大きな晶出物が生成し、機械的性質を劣化させる。Tiは、Ti－B系の微細化剤として添加することができる。この点で、0．03重量％以下のBの共存も許容される。

P：0．01重量％以下，Ca：0．001～0．02重量％

Pを極力少なくすること及びCaの共存によって、初晶Siの発生が抑制され、共晶Siの改良促進が図られ、高強度及び高靱性が維持される。また、ヒケの集中が抑制され、耐圧性が向上する。しかし、0．01重量％を超えるPや0．02重量％を超えるCaは、湯流れ性を悪化させ、湯まわり不良等の鋳造欠陥を発生し、また鋳造組織を不均一にする。

【0009】P／Ca（重量比）：0．5以下

材料の靱性に大きな影響を及ぼす共晶Siの形態は、主としてP／Ca重量比で制御できる。P／Ca重量比の調整による作用自体は本発明者等が特願平4－244259号公報，特願平5－161380号等で紹介したところであるが、P／Ca重量比が0．5以下の場合、共晶Siが微細で球状化し、伸び値が上昇し、靱性が改善される。逆に、0．5を超えるP／Ca重量比では、P量の増加に起因して共晶組織が粗くなり、伸び及び靱性が低下する。

【0010】Ni：0．2～6重量％

必要に応じて添加される合金元素であり、Niを含む金属間化合物を晶出させ、200℃付近における耐熱性，高温強度を改善する。Ni添加の効果は、0．2重量％以上で顕著になる。しかし、6重量％を超える多量のNiを含ませると、Al－Ni－Cu－Si系，Al－Ni－Fe系，Al－Ni－Cu系等の晶出物が多くなり、伸びが低下し、アルミニウム合金を脆くする欠点が現れる。本発明に従ったアルミニウム合金においては、その他の合金元素として、Na，Cr，Zr，Zn等を含むことがある。Naは、共晶Siを微細化する作用を呈するので、鋳造性，型への焼付き性等に悪影響を及ぼさない範囲、すなわち上限を50ppm程度とする範囲での存在が許容される。Crは、0．3重量％以下の含有量で耐摩耗性の向上に寄与する。Zrは、結晶粒微細化に有効であり、0．3重量％以下の量でTiと同時に或いはZr単独で添加することもできる。Znは、不純物として混入してくる元素であり、耐食性の劣化，鋳造割れの発生等の悪影響を及ぼすことから、上限を3重量％に設定することが好ましい。

【0011】晶出物の平均長径：20μm以下　共晶Siの平均長径：10μm以下

冷却速度20℃／秒未満で鋳造する場合、Si含有量が約12重量％以上で初晶Siが晶出する。他方、冷却速度が20℃／秒以上の急冷になるダイカスト等では、初晶Siが晶出開始するSi含有量は、冷却速度の上昇に伴って13～15重量％程度まで移動する。Caの添加は、この移動を助長する。初晶Siのサイズも冷却速度に影響され、冷却速度20℃／秒未満の鋳造では20～100μm以上に、冷却速度20℃／秒以上の鋳造では数μm～30μm程度になる。この点、本発明にあっては、鋳造時の冷却速度を20℃／秒以上に設定していることから、初晶Siが20μm以下に微細化される。その結果、巨大な初晶Siに起因した切削性の劣化が防止される。共晶Siのサイズも、冷却速度，P量，Ca量及びP／Ca比によって影響される。冷却速度が大きい

表3：各種アルミニウム合金の機械的特性

試験番号	２００℃の引張り強さσ_B (N／mm²)	伸び (%)	試験番号	２００℃の引張り強さσ_B (N／mm²)	伸び (%)
1	230	5．4	8	195	2．8
2	250	3．5	9	240	3．4
3	190	2．1	10	170	0．7
5	270	4．2	11	215	2．5
6	255	3．1			

【００１９】表３にみられるように、多量のＦｅを含む試験番号３では、Ａｌ－Ｆｅ系，Ａｌ－Ｆｅ－Ｍｎ系等の晶出物が２０μm以上に大きく晶出し、伸びが低下している。Ｍｎ含有量が多いと、湯流れが悪く鋳造不良であったり（試験番号４，７）、Ｎｉ含有量が多過ぎると、伸び不足を引き起こした（試験番号８）。また、鋳造時の冷却速度が遅いと、試験番号１０にみられるように、金属間化合物が大きく成長し、加工性に劣り、伸びも不足していた。Ｐ／Ｃａ比を高く設定した試験番号１１では、共晶Ｓｉの微細化が不十分であり、低い伸び値を示した。これに対し、合金成分及び鋳造時の冷却速度が本発明で規定した範囲にあるものでは、試験番号１，２，５，６，９の何れにおいても２００℃の引張り強さが２００N／mm² 以上，伸び値が３％以上と優れた高温強度及び靭性をもっていた。

【００２０】

【発明の効果】以上に説明したように、本発明は、含有量が特定された成分・組成をもつＡｌ－Ｓｉ－Ｃｕ－Ｍｇ－Ｆｅ－Ｍｎ（－Ｎｉ）系合金においてＰ含有量，Ｃａ含有量及びＰ／Ｃａ重量比を調整することにより、初晶Ｓｉの発生を抑制し、共晶Ｓｉを微細化し、更に凝固時の冷却速度を規制することによりＦｅ，Ｍｎ，Ｎｉ系晶出物をも微細化している。これによって、高温強度や伸び値で代表される靭性が改善され、ダイカスト用内燃機関部品として好適なアルミニウム合金が得られる。

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ALUMINUM ALLOY FOR DIE CASTING, EXCELLENT IN HIGH-TEMPERATURE STRENGTH AND TOUGHNESS, AND ITS MANUFACTURING METHOD

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Abstract

Objective

To obtain an aluminum alloy for die casting with improved high-temperature strength and toughness.

Constitution

This aluminum alloy contains 1-7% Cu, 10-16% Si, 0.3-2% Mg, 0.5-2% Fe, 0.1-4% Mn, 0.01-0.3% Ti, less than 0.01% P, 0.001-0.02% Ca, and, if necessary, 0.2-6% Ni, and the P/CA weight ratio is adjusted to a range under 0.5. It is cast at a cooling rate higher than 20°C/sec, the average major axis of crystallized material is less than 20 μm, and the average major axis of eutectic Si is less than 10 μm.

Effects

Toughness and high-temperature strength are improved by refining of primary crystal Si, eutectic Si, and crystallized material containing high melting point metals.

Claims

1. An aluminum alloy for die casting excellent in high-temperature strength and toughness characterized by the fact that it contains 1-7 wt% Cu, 10-16 wt% Si, 0.3-2 wt% Mg, 0.5-2 wt% Fe, 0.1-4 wt% Mn, 0.01-0.3 wt% Ti, less than 0.01 wt% P, and 0.001-0.02 wt% Ca, and the P/CA weight ratio is adjusted to a range under 0.5.

2. The aluminum alloy for die casting excellent in high-temperature strength and toughness described in Claim 1, characterized by the fact that it further contains 0.2-6 wt% Ni.

3. The aluminum alloy for die casting excellent in high-temperature strength and toughness described in Claim 1 or 2, characterized by the fact that the average major axis of crystallized material is less than 20 μm, and the average major axis of the eutectic Si is less than 10 μm.

4. A method for the manufacture of a die cast product by die casting an aluminum alloy melt having the composition described in Claim 1 or 2 at a cooling rate higher than 20°C/sec.

5. The die cast product manufactured by the method of Claim 4.

Detailed explanation of the invention

[0001]

Industrial application field

The present invention relates to an aluminum alloy for die casting excellent in high-temperature strength and toughness that is appropriate for pistons, con rods, cylinder blocks, cylinder heads and so on used in diesel engines, gasoline engines and other internal combustion engines, and its manufacturing method.

[0002]

Prior art

Eutectic crystal or super-eutectic crystal Al-Si alloys containing greater than about 10 wt% Si have small coefficients of thermal expansion and excellent wear resistances. Furthermore, if the Si content is increased, primary crystal Si of a high hardness is crystallized during the solidification of the melt. Therefore, they are used as pistons of internal combustion engines, compressor parts and a variety of other machine parts that require wear resistance. Among these, AC8A has been used as a typical Al-Si alloy. Recently, for internal combustion engines, there has been a trend in the effective utilization of energy resources and an increase in combustion efficiency. If the combustion efficiency is to be improved, the combustion temperature will need to be increased. In connection with this, a high strength at a high temperature in the vicinity of 200°C is required as a property of the material for a variety of parts, especially pistons, incorporated in internal combustion engines. For other parts used in internal combustion engines, an improvement in wear resistance is also pursued in the same manner.

[0003]

As an aluminum alloy for piston use with high-temperature strength, a material having sufficient high-temperature strength and heat-resistant impact characteristics even by the T_5 heat treatment has been disclosed in Japanese Kokai Patent Application No. Sho 57[1982]-79410. For this alloy, together with the regulation of the Si content to the range of 8.5-13.5 wt%, by the addition of Sb, the eutectic Si is improved. Furthermore, in Japanese Kokai Patent Application No. Sho 55[1980]-24784, during the manufacture of a piston by casting of an Fe base material with an Al-Si-Cu-Mg alloy, the heat-resistant impact characteristics are improved by a heat treatment at 480-520°C for 1-8 h after casting. In general, in Al-Si type material excellent in high-temperature strength, small amounts of Ni, Mn, Fe, Cr, Zr and other high melting point components are contained in an Al-Si-Cu-Mg type alloy as a base. The high melting point components are crystallized as microcrystallized portions during solidification of the melt. They

exhibit an effect of hindering high-temperature deformation of the Al alloy. However, with an increase in the content of high melting point components, coarse intermetallic compounds are formed in a large quantity. The strength is easily deteriorated. In addition, elongation is decreased. Sufficiently satisfactory characteristics are not provided to the parts requiring toughness.

[0004]

Problems to be solved by the invention

However, the Al-Si type alloy has reached a level at which the most basic material characteristics cannot be improved by conventional adjustment of alloy components or by structural improvement by added components. Therefore, it is necessary to develop a material exhibiting characteristics, especially high-temperature characteristics, that upgrade the current situation to a large extent by improvement of the composition and the structure by a method not available currently. As the most difficult point in the problem, a coarse crystallized material is formed and strength deterioration occurs with an increase in the amount of addition of high melting point components effective in the improvement of high-temperature characteristics. Thus, if an upgrade in characteristics can be achieved by increasing the amount of addition of high melting point components without causing strength deterioration, an Al-Si type alloy satisfying material characteristics required for a variety of applications can be obtained. The present invention has been proposed in response to such a requirement. The objective is to provide an aluminum alloy excellent in high-temperature strength and toughness in the form of a structure obtained by the crystallization of high melting point components as microfine intermetallic compounds stable at a high temperature by means of casting a specific Al-Si type alloy for the component system in a die casting or casting method having a greater cooling rate.

[0005]

Means to solve the problems

The aluminum alloy for die casting, in order to achieve its objective, is characterized by the fact that it contains 1-7 wt% Cu, 10-16 wt% Si, 0.3-2 wt% Mg, 0.5-2 wt% Fe, 0.1-4 wt% Mn, 0.01-0.3 wt% Ti, less than 0.01wt% P, and 0.001-0.02 wt% Ca, and the P/CA weight ratio is adjusted to a range under 0.5. This aluminum alloy can further contain 0.2-6 wt% Ni. The aluminum alloy for die casting according to the present invention is obtained by casting of the aluminum alloy melt having the composition mentioned previously at a cooling rate higher than 20°C/sec. The average major axis of the crystallized material is controlled to less than 20 μm, and the average major axis of the eutectic Si is controlled to less than 10 μm.

[0006]

The alloy elements contained in the aluminum alloy of the present invention, their contents and so on will be explained in the following.

1-7 wt% Cu

This is an alloy element that is effective in improving the high-temperature strength and the high-temperature fatigue strength. The effect of the Cu addition becomes pronounced in a solid solution state. If the Cu content is less than 1 wt%, the high-temperature strength will be insufficient. However, if Cu is contained at a large amount exceeding 7 wt%, Al_2Cu and other large crystallized materials will be formed and casting cracking will occur easily. Furthermore, even if Cu is added at a greater amount, a corresponding increased improvement in strength cannot be achieved.

10-16 wt% Si

This alloy element is required to form eutectic Si effective in improving the wear resistance and decreasing the coefficient of thermal expansion. It also exhibits an effect in improving the melt flow. Furthermore, Mg_2Si effective in age hardening is also formed by reaction with the coexisting Mg. If the Si content does not reach 10 wt%, the wear resistance and the high-temperature strength will be lower than the target values and the coefficient of thermal expansion will be high. On the other hand, at an Si content exceeding 16 wt%, the size of the primary crystal Si will increase and the degree of dispersion will be large. As a result, this will lead to a reduction in the high-temperature strength due to stress concentration.

[0007]

0.3-2 wt% Mg

This forms Mg_2Si, which is effective in age hardening by bonding with Si. If the Mg content is below 0.3 wt%, a sufficient age hardening effect cannot be achieved. On the other hand, at an Mg content exceeding 2 wt%, a large amount of Mg_2Si will be crystallized during casting and the mechanical properties will decrease.

0.5-2 wt% Fe

This alloy element is effective in improving the high-temperature strength. The effectiveness becomes pronounced at an Fe content greater than 0.5 wt%. Furthermore, baking of the mold during die casting can be prevented. Fe is crystallized as a variety of intermetallic compounds and the strength at high temperatures is improved. However, at an Fe content

exceeding 2 wt%, the high-temperature strength is decreased instead because coarse intermetallic compounds containing Fe are crystallized.

0.1-4 wt% Mn

This is crystallized as Al-Mn-Si, Al-Fe-Mn-Si and other intermetallic compounds, and the wear resistance is improved. Furthermore, this alloy element is effective in improving the high-temperature strength in the vicinity of 200°C. In order to achieve such an effect, more than 0.1 wt% Mn is required. However, a high Mn content exceeding 4 wt% will lead to a reduction in elongation and other defects because of the formation of many very large areas of crystallized material.

[0008]

0.01-0.3 wt% Ti

This alloy element is effective in refining α-Al and in homogenizing the material. If the Ti content is more than 0.01 wt%, α-Al becomes microcrystal particles with a diameter less than 10 mm and the effectiveness due to refining is pronounced. However, at a Ti content exceeding 0.3 wt%, a large crystallized material of the Al-Ti type is formed and the mechanical properties deteriorate. Ti can be added as a Ti-B type refining agent. In this aspect, the coexistence of B at less than 0.03 wt% is permissible.

Less than 0.01 wt% P, and 0.001-0.02 wt% Ca

By decreasing P as much as possible and allowing the coexistence of Ca, formation of the primary crystal Si is inhibited, improvement of the eutectic Si is promoted, and the high strength and the high toughness are maintained. Furthermore, the concentration of hike [transliterated] is inhibited and the pressure resistance is upgraded. However, with P exceeding 0.01 wt% or Ca exceeding 0.02 wt%, melt flow characteristics will deteriorate and inferiority around the melt and other casting defects will occur. Furthermore, the cast texture will not be uniform.

[0009]

P/Ca (weight ratio) under 0.5

The state of the eutectic Si that affects the toughness of the material to a large extent is controlled mainly by the P/Ca weight ratio. The effect itself due to the adjustment of the P/Ca weight ratio is in the same manner as that disclosed by Japanese Patent Application Nos. Hei 4[1992]-244259, Hei 5[1993]-161380, and so on by the present inventors. In the case of the P/Ca weight ratio being under 0.5, the eutectic Si is spheroidized in a microfine fashion, the elongation value is increased, and the toughness is improved. On the other hand, at a P/Ca weight ratio

exceeding 0.5, the eutectic texture is coarse, and the elongation and toughness are decreased because of an increase in the amount of P.

[0010]

0.2-6 wt% Ni

This alloy element is added if necessary. Intermetallic compounds containing Ni are crystallized, and the heat resistance and the high-temperature strength in the vicinity of 200°C are improved. The effect of the Ni addition is pronounced at more than 0.2 wt%. However, if a large amount of Ni exceeding 6 wt% is contained, crystallized materials of Al-Ni-Cu-Si, Al-Ni-Fe, Al-Ni-Cu and so on will increase. Disadvantages like reduction in elongation and embrittlement of the aluminum alloy will appear. In the aluminum alloy according to the present invention, Na, Cr, Zr, Zn and so on as other alloy elements may be contained. Na exhibits an effect in the refining of the eutectic Si. This is preferably present in a range without causing adverse effects on casting characteristics, baking of the mold, and so on, that is, in the range with 50 ppm or so as the upper limit. Cr contributes to an improvement in the wear resistance at a content less than 0.3 wt%. Zr is effective in refining the crystal to microparticles. At an amount less than 0.3 wt%, Zr may be added together with Ti or added alone. Zn is present as an impurity. Since this causes adverse effects like deterioration by corrosion, the formation of casting cracks and so on, the upper limit is preferably set at 3 wt%.

[0011]

The average major axis of the crystallized material less than 20 μm, and the average major axis of the eutectic Si less than 10 μm

In the case of casting at a cooling rate less than 20°C/sec, the primary crystal Si will crystallize at an Si content greater than about 12 wt%. On the other hand, for the die cast or the like quenched at a cooling rate higher than 20°C/sec, the Si content at which the primary crystal Si begins to crystallize shifts to 13-15 wt% or so. The addition of Ca enhances this shift. The size of the primary crystal Si is also affected by the cooling rate. It is 20-100 μm or higher in casting at a cooling rate less than 20°C/sec, and a few μm to 30 μm or so in casting at a cooling rate higher than 20°C/sec. As a result, the deterioration in cutting characteristics caused by the enormous primary crystal Si is prevented. The size of the eutectic Si is also affected by the cooling rate, the P content, the Ca content, and the P/Ca ratio. It is in a fine, granular shape when the cooling rate is high. It easily becomes a needle shape at a low cooling rate. If the P/Ca ratio is more than 0.5, the eutectic Si has a needle shape. At a P/Ca ratio less than 0.5, there is a tendency in which it becomes granular. In order to obtain a good toughness, microfine, granular

eutectic Si is preferred. When the eutectic Si has an average major axis exceeding 10 μm, the elongation is decreased.

[0012]

If intermetallic compounds, in addition to the primary crystal Si and the eutectic Si, are crystallized at sizes exceeding 20 μm, an adverse effect of deterioration in the high-temperature strength is exhibited. Therefore, in the present invention, in order to maintain the high-temperature strength, if necessary, the average major axis of the crystallized material is specified at less than 20 μm. In the case of a low cooling rate, compounds of high melting point metals are developed to a large extent. There are cases in which they reach a few tens to a few hundreds of μm. The compounds take needle shapes, Chinese script shapes, amorphous shapes and a variety of other shapes. In the case of a large size, stress concentration occurs in any case, and the strength is decreased easily. In particular, Al-Fe type compounds easily form needles and the effect is high. In the case of a high cooling rate, the development of the compounds is inhibited and they easily form needles in which stress concentration occurs difficultly.

Cooling rate higher than 20°C/sec during casting

In order to improve the high-temperature strength by the refining of intermetallic compounds containing Fe, Ni, Mn, and other high melting point metals, it is necessary to set the cooling rate during casting at more than 20°C/sec. If the cooling rate is less than 20°C/sec, coarse intermetallic compounds with an average length exceeding 20 μm are crystallized easily. This causes a reduction in elongation, strength, etc. In the present invention, thin-wall rapid cooling mold casting in addition to die casting can also be adopted. Pistons and other base shape materials can be cast. The base shape materials can be subjected to machine processing in a state as such or, if necessary, a solution treatment or an aging treatment may also be carried out.

[0013]

Application examples

Aluminum alloy melts containing 13.0 wt% Si, 5.5 wt% Cu, 0.75 wt% Mg, 0.1 wt% Ti, 0.0006 wt% B, 0.05 wt% Cr, 1.0 wt% Zn, 0.05 wt% Zr, 0.006 wt% Ca, and 0.001 wt% P, with the P/Ca weight ratio set at 0.17, and with adjustments of Fe, Mn, and Ni as shown in Table 1 were prepared. In Sample No. 11 shown in Table 1, Ca was 0.001 wt%, P was 0.002 wt%, and the P/Ca ratio was 2.0.

[0014]

Table 1 Fe, Mn and Ni contents of aluminum alloy melts (wt%)

① 試験番号	Fe	Mn	Ni	試験番号	Fe	Mn	Ni
1	0.8	0.3	0.05	7	1.5	5*	1
2	1.5	3	0.05	8	1.5	3	7*
3	2.5*	3	0.05	9	1.5	3	5
4	1.5	5*	0.05	10	1.5	3	5
5	0.8	1	1	11	0.8	0.3	0.05
6	1.5	3	5				

Key: 1 Sample No.

Symbol * represents a value outside the range specified in the present invention.

[0015]

Each of the aluminum alloy melts was melted at 760°C, and the melt temperature was lowered to 720°C. Each was cast into JIS 4 boat molds as in conventional mold casting, and into die casting machine TP molds for die casting. TP molds capable of being adopted as tensile test specimens with a parallel part diameter of 10 mm and a length of 70 mm and wear test specimens of 50 mm x 50 mm x 6 mm were used. The cooling rate was adjusted so that the casting mold could be heated to 150°C. It was set at 5°C/sec for mold casting and at 50°C/sec for die casting. The texture of the ingot obtained was observed. The results obtained in investigating the effects of casting conditions on the crystallized materials are shown in Table 2. In Test Sample 9, the cooling rate was set at 25°C/sec due to the use of a JIS4 boat mold made of pure copper.

[0016]

Table 2. Relationship between casting conditions and crystallized materials

① 試験番号	② 鋳造時の冷却速度℃／秒）	③ 初晶Ｓｉの晶出状態	④ 共晶Ｓｉの平均長径（μｍ）	⑤ 他の晶出物の平均長径（μｍ）	⑥ 区分
1	50	⑦僅少	＜5	＜20	本発明例 ⑧
2	50	僅少	＜5	＜20	本発明例
3	50	僅少	＜5	＞20	比較例 ⑨
4	50	湯流れが悪く鋳造不可 ⑩			比較例
5	50	⑦僅少	＜5	＜20	本発明例 ⑧
6	50	僅少	＜5	＜20	本発明例
7	50	湯流れが悪く鋳造不可 ⑩			比較例 ⑨
8	50	⑦僅少	＜5	＞20	比較例
9	25	僅少	2～10	＜20	本発明例 ⑧
10	5	⑪若干あり	5～20	＞20	比較例 ⑨
11	50	⑦僅少	5～20	＜20	比較例

Key:
1 Test No.
2 Cooling rate during casting (°C/sec)
3 Crystallized state of the primary crystal Si
4 Average major axis of eutectic Si (μm)
5 Average major axis of other crystallized materials (μm)
6 Distinction
7 Slight
8 Example of the present invention
9 Comparative example
10 Melt flow was poor and casting was impossible
11 Some

[0017]

For the mold cast material obtained, a solution treatment was carried out at 500°C x 6 h. After hardening in warm water at 60°C, an aging treatment was performed at 220°C x 6 h. This was followed by air cooling. On the other hand, for the die cast material, an aging treatment was performed at 220°C x 6 h. This was also followed by air cooling. From each of the alloys after the heat treatment, toughness and wear test specimens and high temperature tensile test specimens were obtained by cutting. The high temperature test was done on the test specimens after preliminary heating at 200°C for 100 h. The test results for the tensile strength and the elongation value are shown in Table 3.

[0018]

Table 3. Mechanical characteristics of a variety of aluminum alloys

① 試験番号	② 200℃の引張り強さσ_B (N/mm²)	③ 伸び (%)	① 試験番号	② 200℃の引張り強さσ_B (N/mm²)	③ 伸び (%)
1	230	5.4	8	195	2.8
2	250	3.5	9	240	3.4
3	190	2.1	10	170	0.7
5	270	4.2	11	215	2.5
6	255	3.1			

Key: 1 Test No.
2 Tensile strength at 200°C
3 Elongation (%)

[0019]

As shown in Table 3, for Test Sample No. 3 containing a large amount of Fe, crystallized materials of the Al-Fe type, the Al-Fe-Mn type and so on were formed to large sizes greater than 20 μm, and the elongation was decreased. If the Mn content was high, the melt flow was poor and casting was inferior (Test Sample Nos. 4 and 7). If the Ni content was excessively high,

insufficient elongation occurred (Test Sample No. 8). Furthermore, if the cooling rate during casting was low, as shown by Test Sample No. 10, intermetallic compounds grew to a large extent, processing characteristics were poor, and the elongation was insufficient. For Test Sample No. 11 with a P/Ca ratio set at a high value, refining of the eutectic Si was insufficient and a low elongation value was exhibited. In contrast to these, for Test Sample Nos. 1, 2, 5, 6, and 9 in the ranges of the alloy components and the cooling rates during casting specified in the present invention, excellent high-temperature strength and toughness were obtained with a tensile strength greater than 200 N/mm^2 and an elongation greater than 3% at 200°C.

[0020]

Effects of the invention

As explained previously, in the present invention, by adjustment of the P content, the Ca content and the P/Ca weight ratio in the Al-Si-Cu-Mg-Fe-Mn(-Ni) alloy having components with specified contents and compositions, the formation of primary crystal Si is inhibited, and the eutectic Si is microfined. Furthermore, by regulation of the cooling rate during solidification, the Fe, Mn, and Ni crystallized materials are also microfined. Because of this, the toughness represented by the high-temperature strength or the elongation value is improved. An aluminum alloy appropriate as die cast internal combustion engine parts can be obtained.